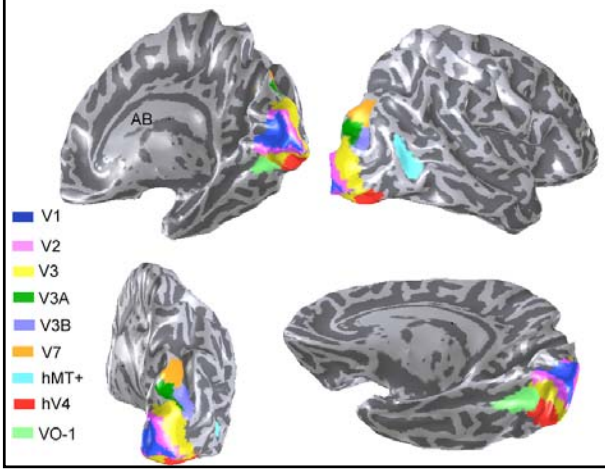
Making sense: Foundations of vision

Brian Wandell
Stanford University

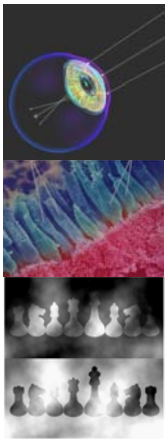


Readings

• Foundation of Vision (1995) Wandell

• Visual Field Maps in Human Cortex (2007)
B. A. Wandell, S.O. Dumoulin and A. A. Brewer
Neuron, V. 56 , p. 366-383

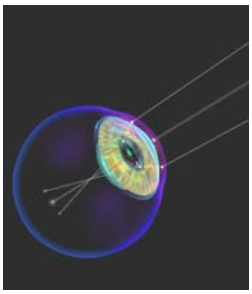
Making sense: Foundations of vision



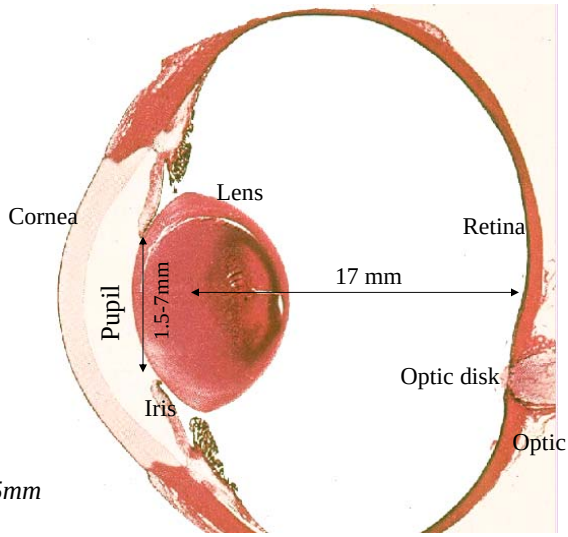
• Visual cortex reflects how light is encoded in the eye
  – Wavelength-dependent blurring
  – Receptor sampling,
  – Color-matching and opponent-color
• Retinal circuitry and early wiring
  – Multiple classes of RGC
  – Hemifields and maps
• Visual cortex – specializations for interpretation
  – Visual field maps
  – The story of an achiasmic subjects

Image formation

- What is the quality of the optics of the human eye?
- How can we measure it and describe it empirically?

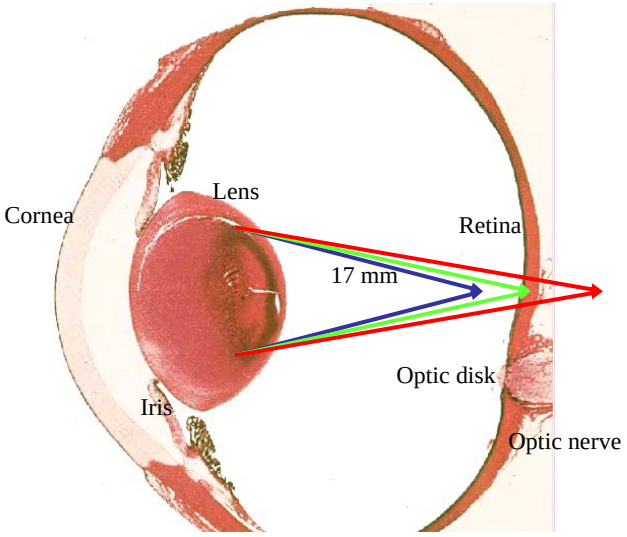


Human eye in cross-section

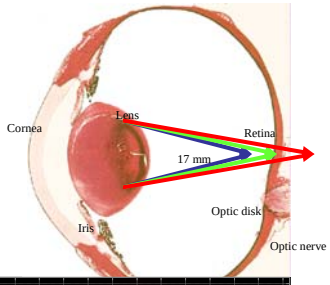


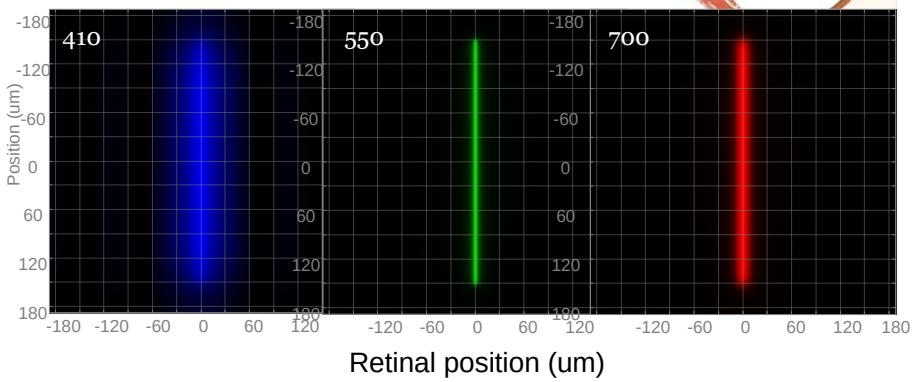
F-number ~ 2.4-11
Retinal thickness ~ 0.5mm

Chromatic aberration is a differences in optical focus across wavelength



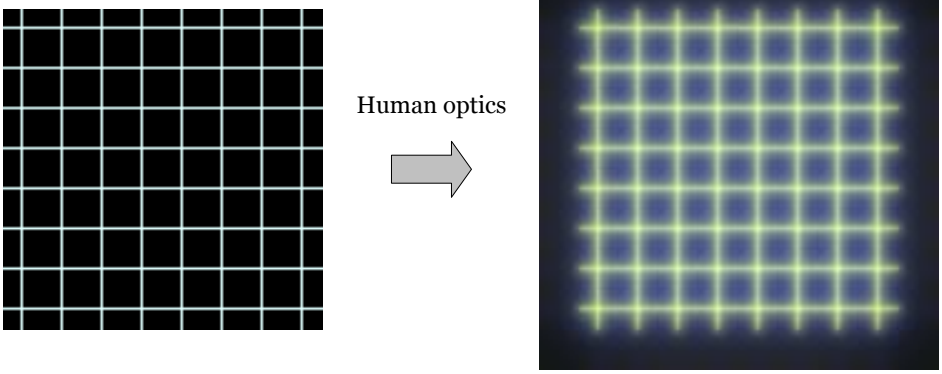
Retinal blur differs by wavelength



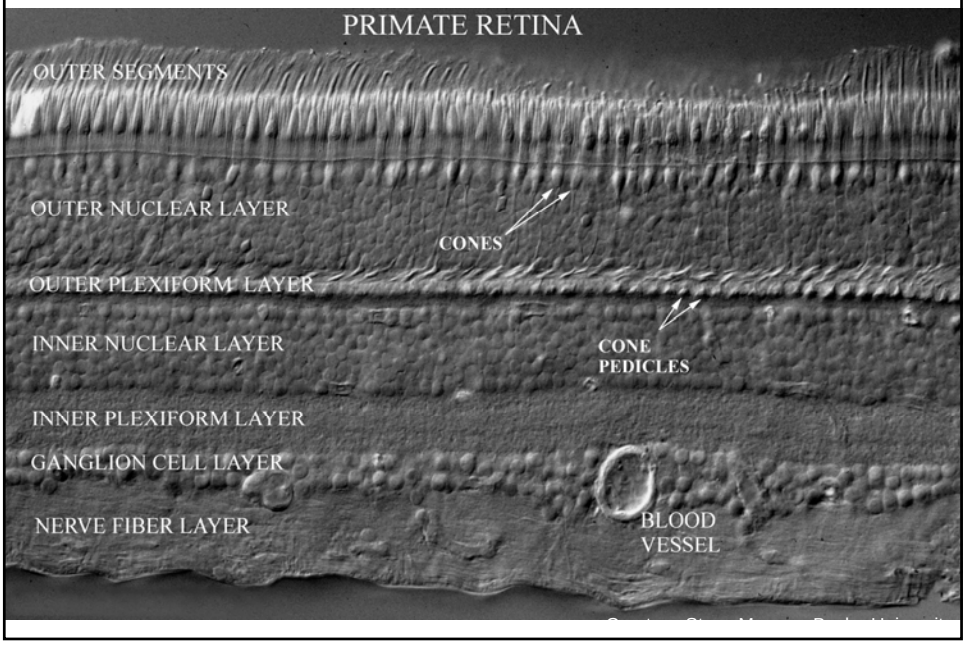


Short wavelength light spreads a lot

Broadband radiance produces chromatic irradiance



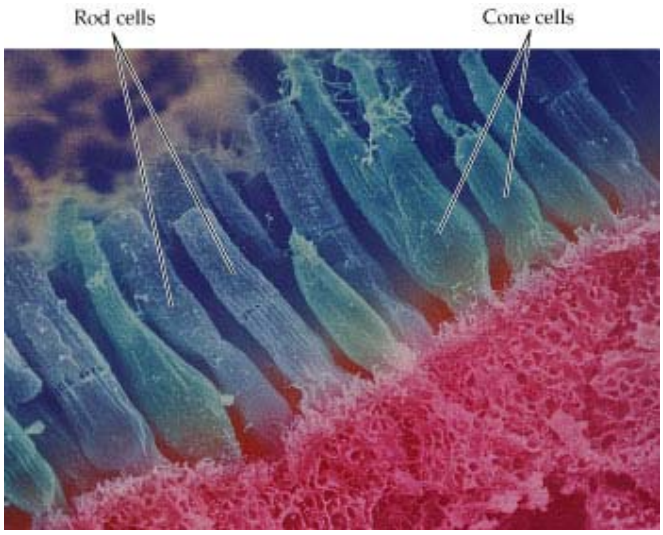
Human peripheral retinal



http://ebooks.bfwpub.com/life.php Figure 45.18

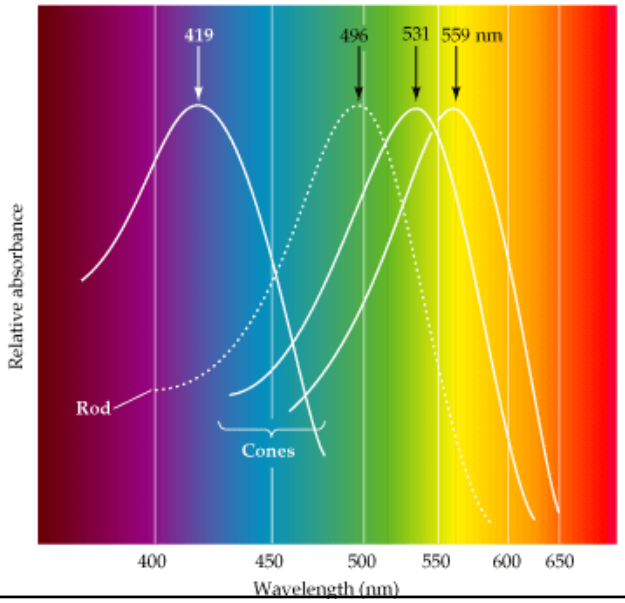
Rods and cones

Rods and cones seen through a scanning electron microscope. Each rod is about one micron across.



Human receptor wavelength absorptions

(LIFE ebook, Figure 45.19)



Ratio of L/M cones differs greatly between normals

Hofer, H. et al. J. Neurosci. 2005;25:9669-9679

And yet, color appearance across observers is quite consistent

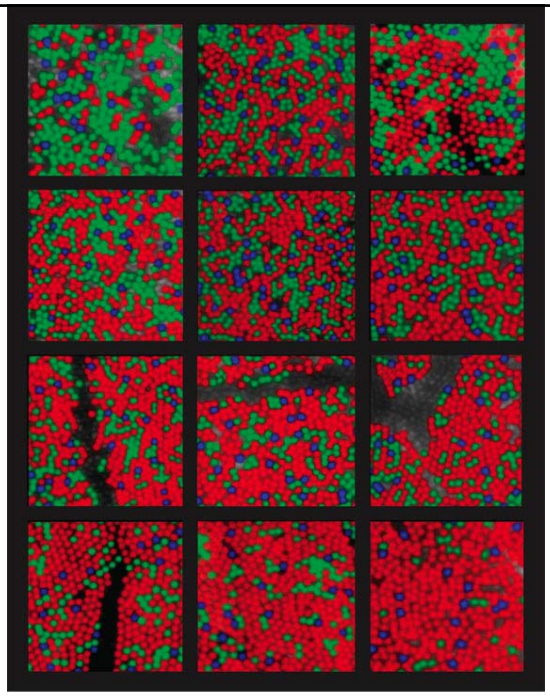
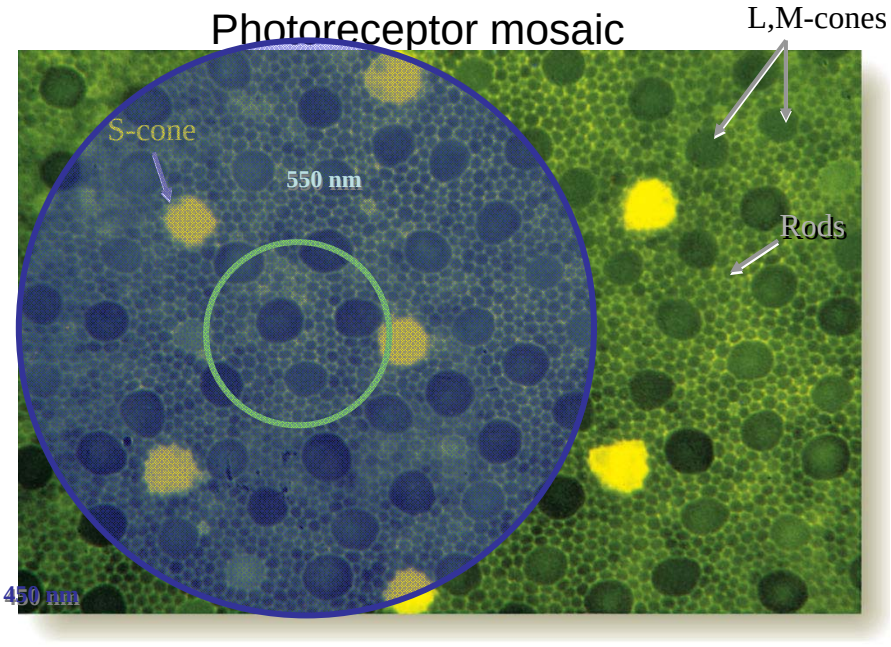
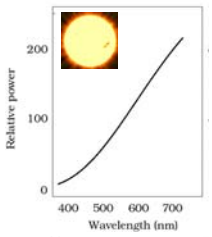


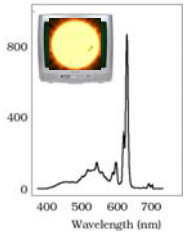
Fig. 7-CO, p. 140

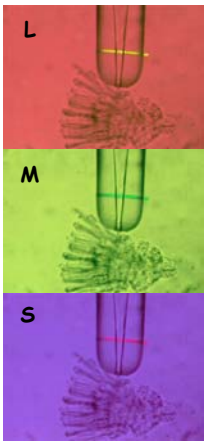
Photoreceptor mosaic

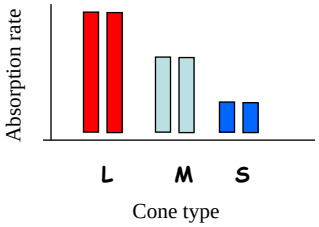


Color-matching: Stimuli causing equal cone absorptions match perceptually





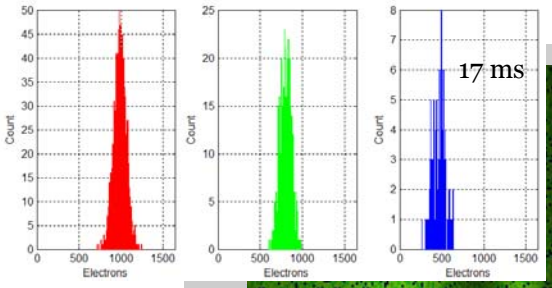


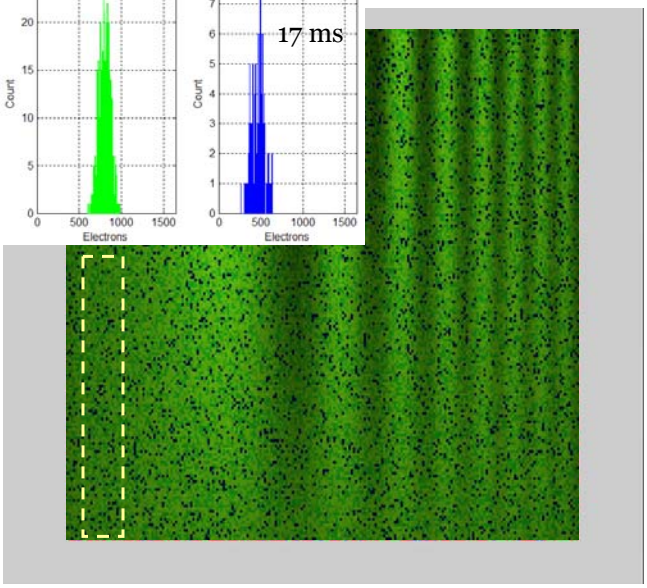


This is really important for all color technologies

ISET

Simulations: Cone absorptions are Poisson



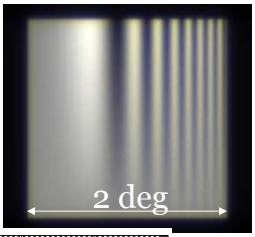


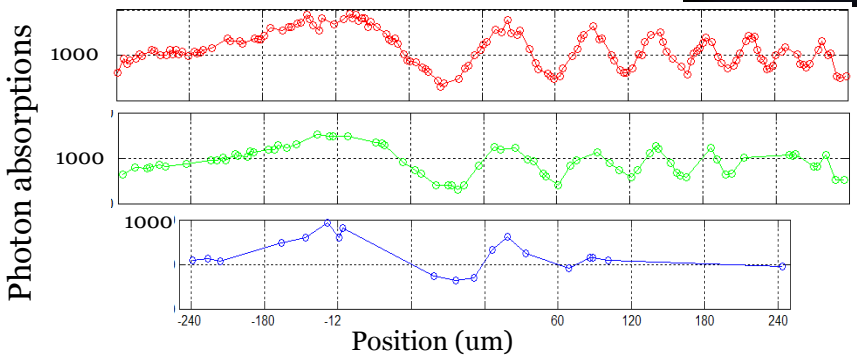
- Encoding has 3 cone types
- Small absorption rate (Poisson noise)

ISET

Simulations: Spatial encoding varies with cone type and wavelength

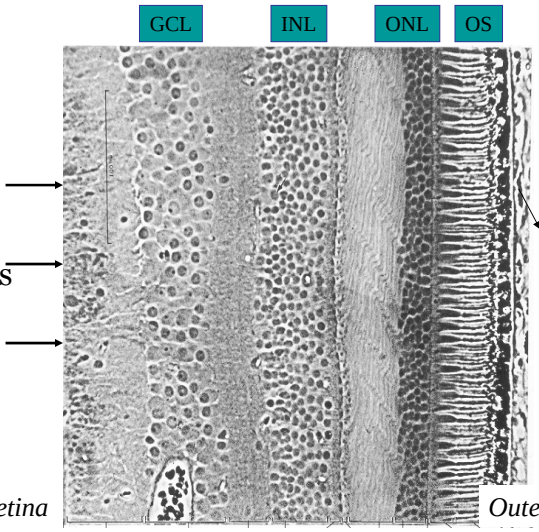
- 7:4:1 LMS sampling ratio, 2.5 um
- S: Chromatic aberration and under-sampling
- M: Under-sampling





Primate retina (peripheral)

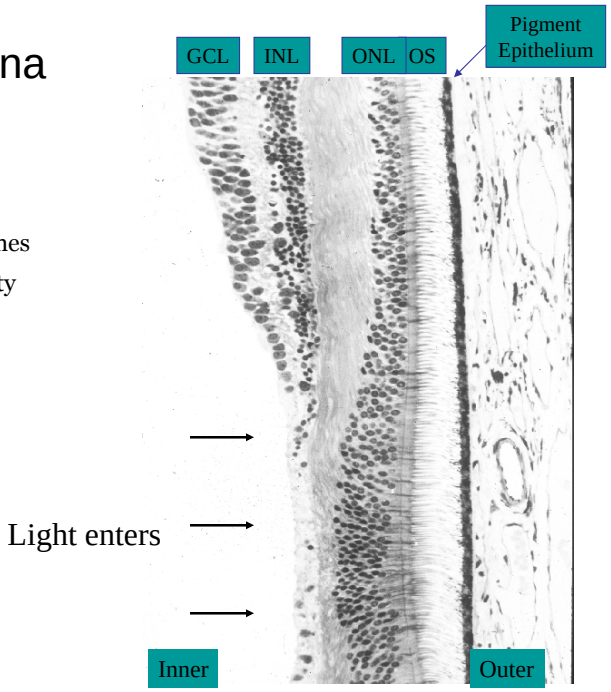
- Poor acuity and color
- Good flicker motion



Dowling

Primate retina (central)

- Contains mainly cones
- Specialized for acuity and color



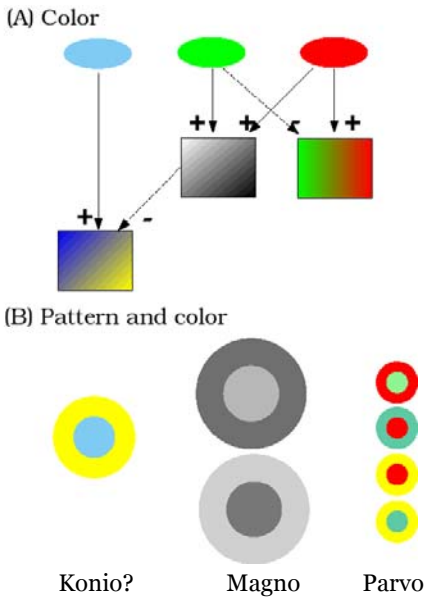
Curcio

Cone signals are summed and differenced in the retina: These opponent signals are reflected in perceptual experience

Retina
L,M,S cones
Midget
Parasol
Bistratified

LGN
Parvocellular
Magnocellular
Koniocellular

Cortex
Visual areas (V4, TEO)
Visual streams (V1 blobs, V2 stripes)

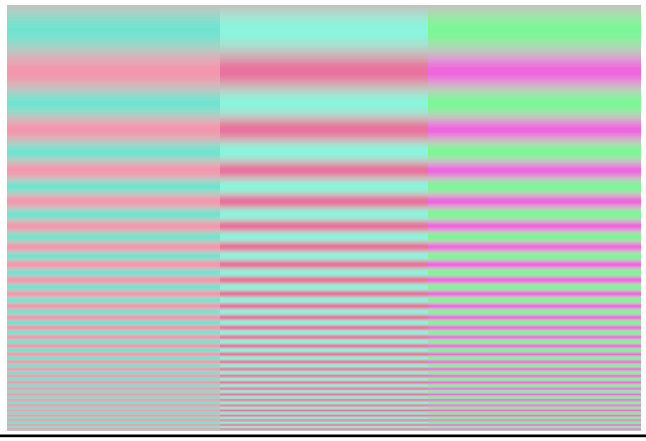


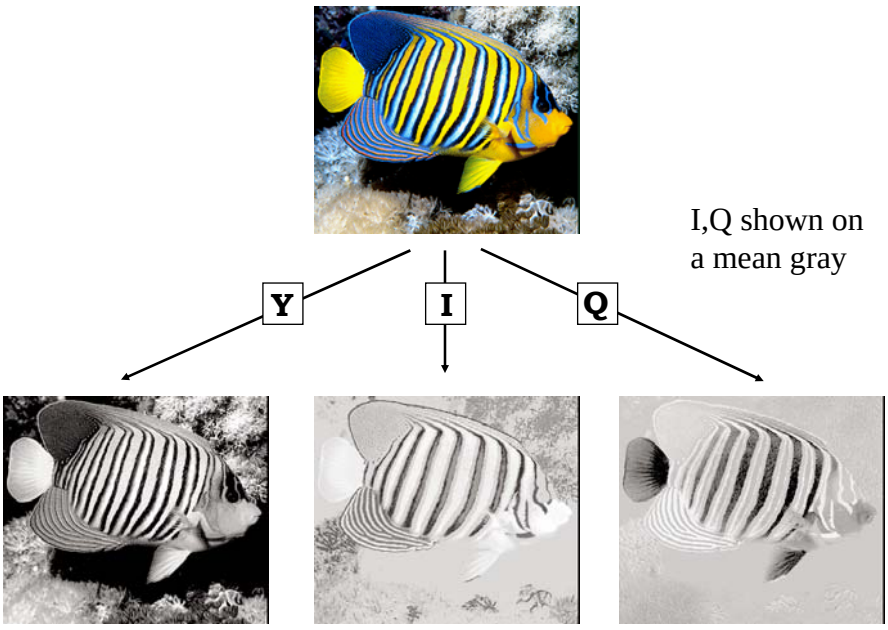
Spatial and temporal differences in the remixed color signals are significant

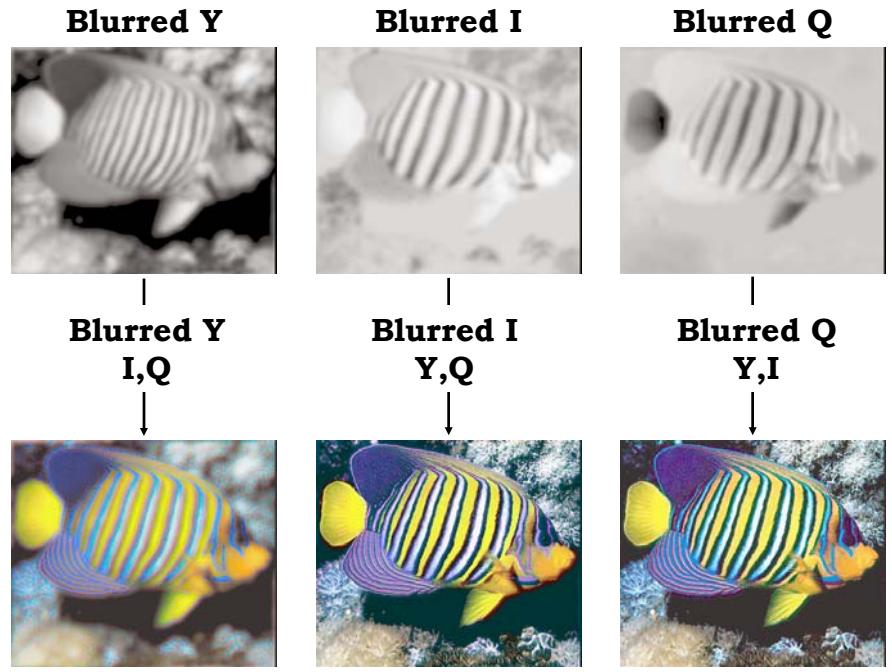
Reduced luminance contrast

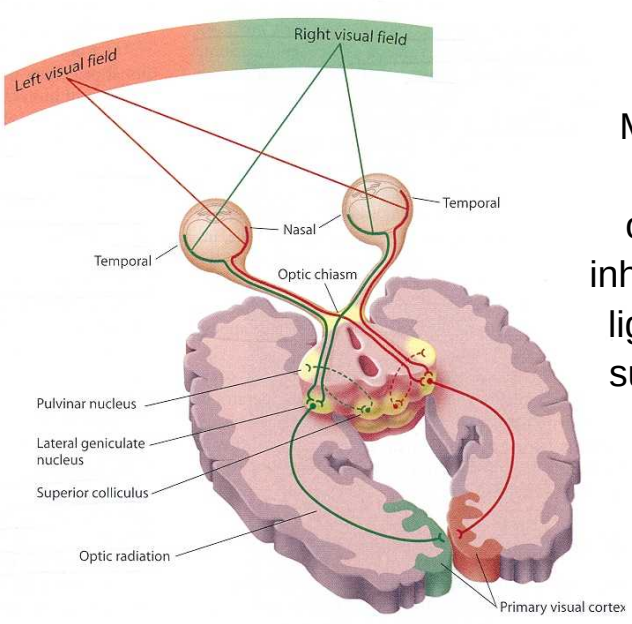
Original

Reduced blue-yellow contrast





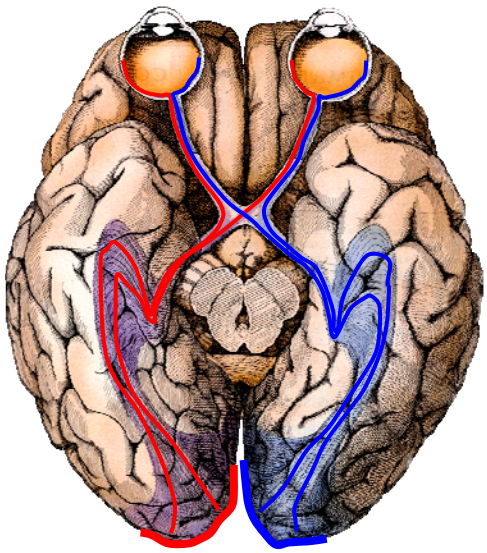




Major features of early cortical organization are inherited from retinal light encoding and subsequent wiring

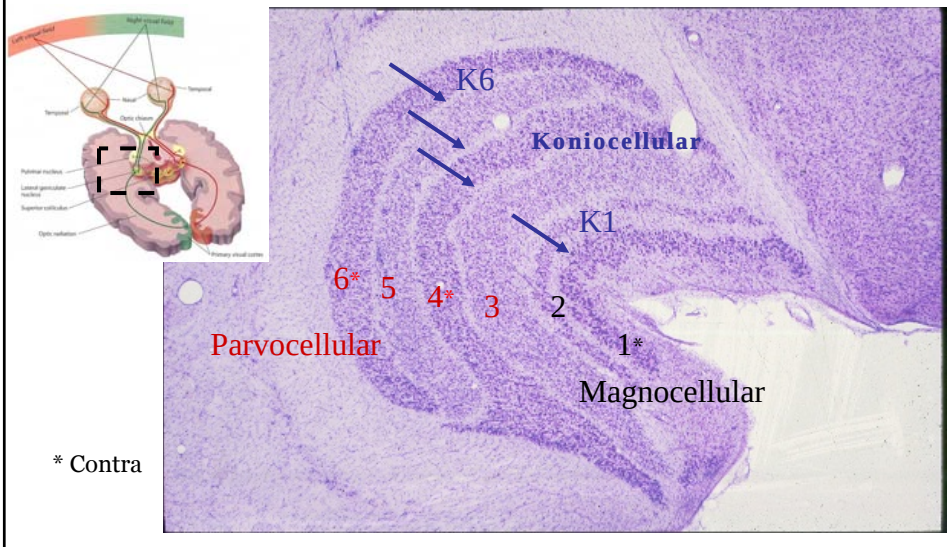
The cortical hemifield representations arise from early wiring circuitry

Chiasmal crossing molecules (Mason)



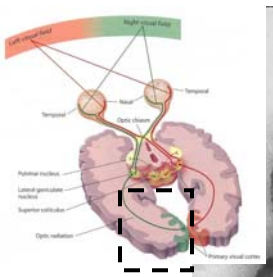
Right visual field
Left visual field

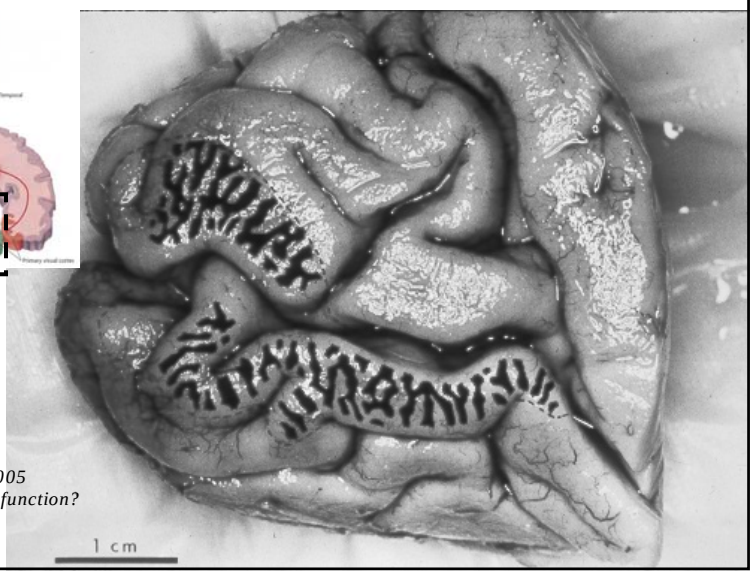
Cell type and ocular layers are present in the LGN



* Contra

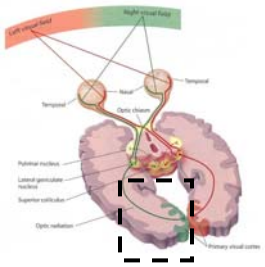
And in V1 (ocular)

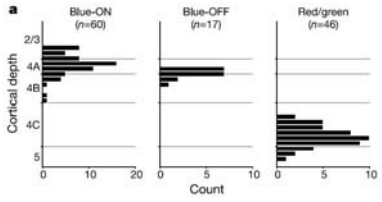


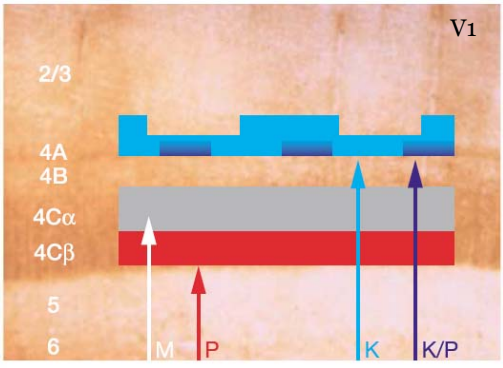


Horton & Adams, 2005
Structure without a function?

And in V1 input (cell types)





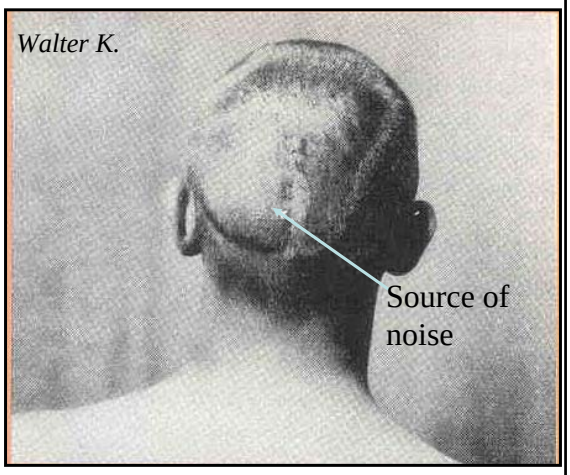


Increases in oxygenated blood flow to active cortical regions of cortex

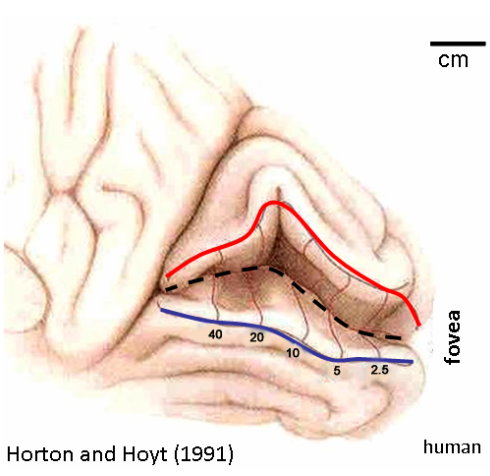
J.F. Fulton, M.D. (1928)

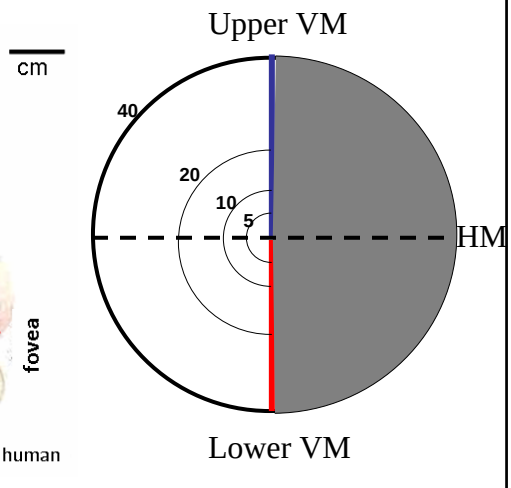
Operation
On turning down a left occipital bone flap,a large angry-looking angioma arteriale racemosum of the left occ. Lobe was disclosed which extensively involved the visual cortex. The haemorrhage occasioned by the bone flap was so excessive that the operation had to be abandoned without touching the tumour. A decompression, however, was made. The patient was discharged … with greatly improved vision.

- *Subject noted that "the noise in the back of his head increased in intensity when he was using his eyes."*
- *No increase for hearing, touch or smell*
- *Increased more when he tried harder*



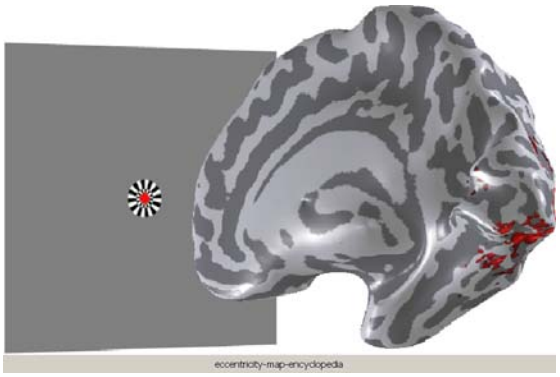
Primary visual cortex (V1) contains a visual field map





Human eccentricity mapping

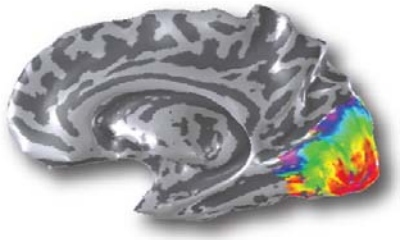
(Engel et al., 1994,1997; Sereno; DeYoe; Others)

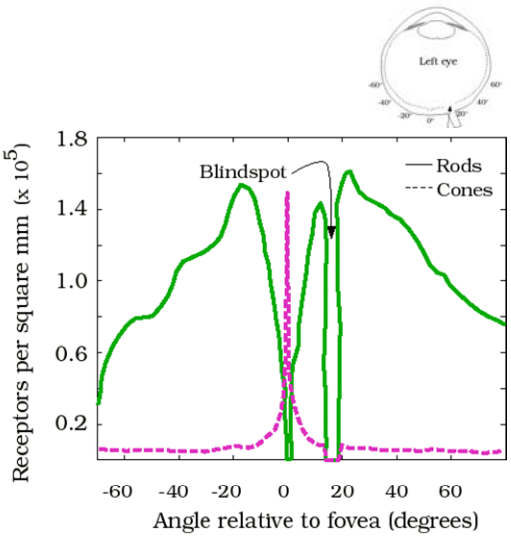


Pseudo-color representation of visual field map: Expanded foveal representation

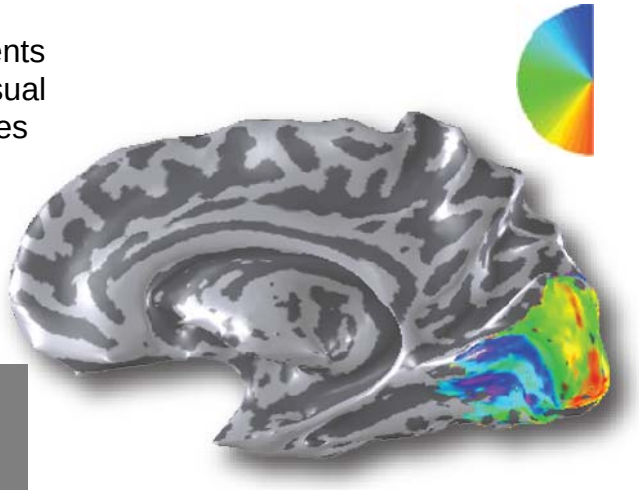
20 deg

Spatial density of cones (not rods) matches expansion of fovea in the cortical map

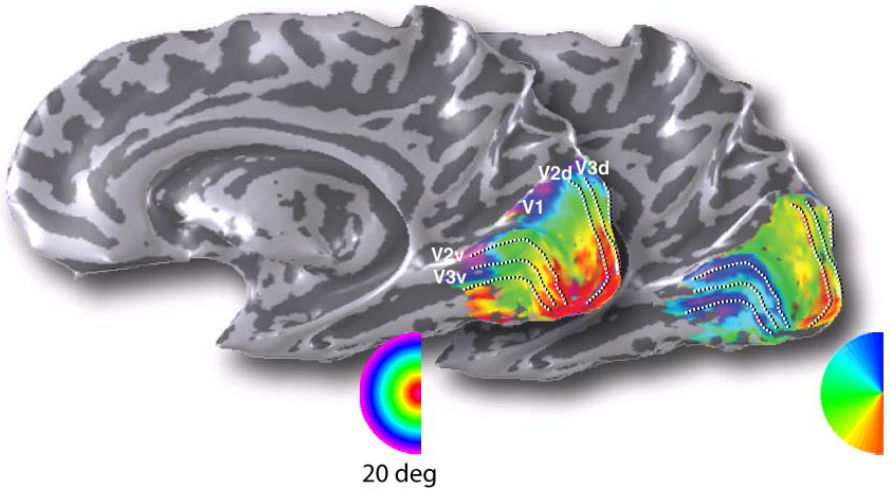




Angular measurements sharply delineate visual field map boundaries

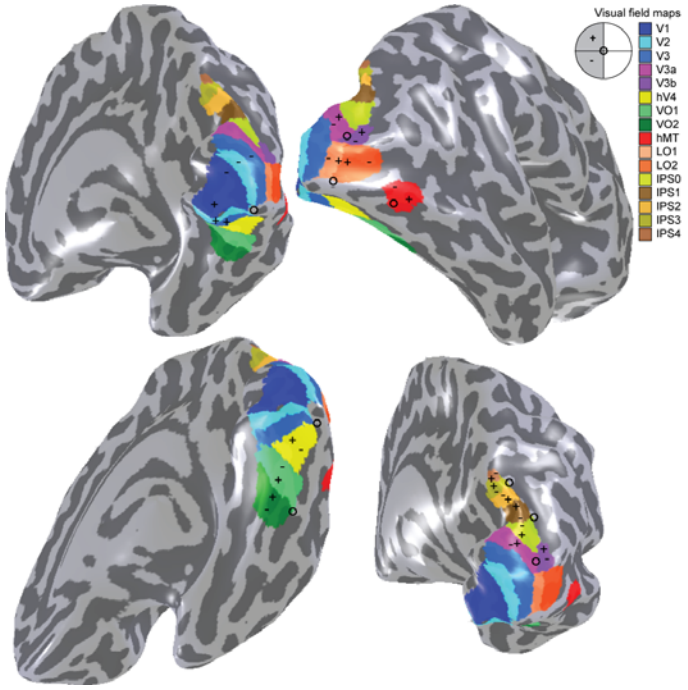


Combining the data yields maps



More than sixteen visual field maps

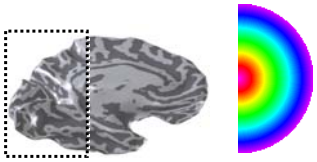
Wandell, Dumoulin, Brewer (2007) Neuron



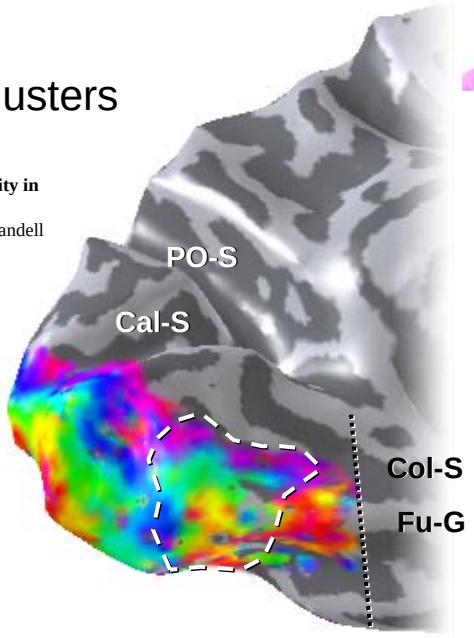
Visual field map clusters

Brewer

Visual field maps and stimulus selectivity in human ventral occipital cortex.
A.A. Brewer, J. Liu, A.R. Wade, B.A. Wandell
Nat Neurosci., vol. 8 no. 8, pp. 1102-9



Coherence = 0.25

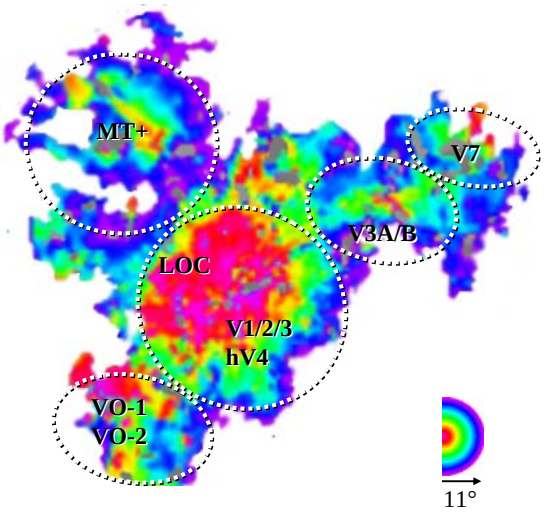


Visual field map clusters

(Wandell et al., 2005, Phil Trans Roy Soc)

Clusters

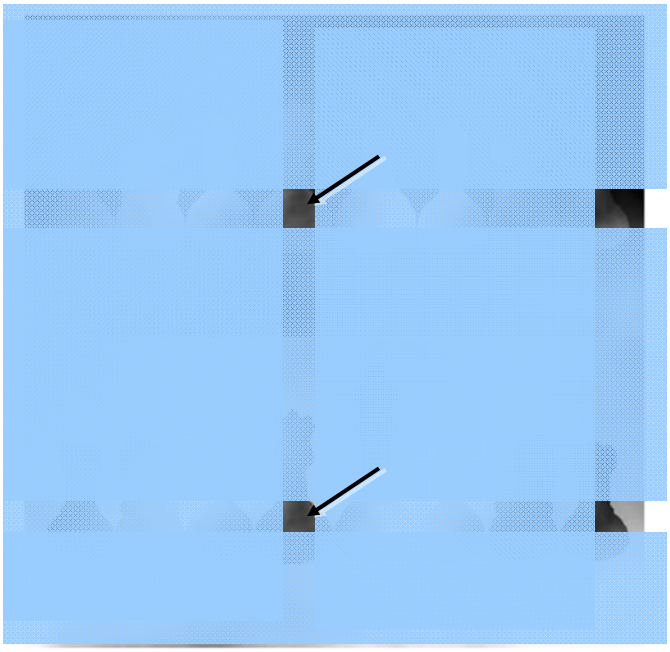
- share a common circular or semi-circular eccentricity map.
- contain multiple angle maps within the eccentricity representation.
- may share similar computational resources.

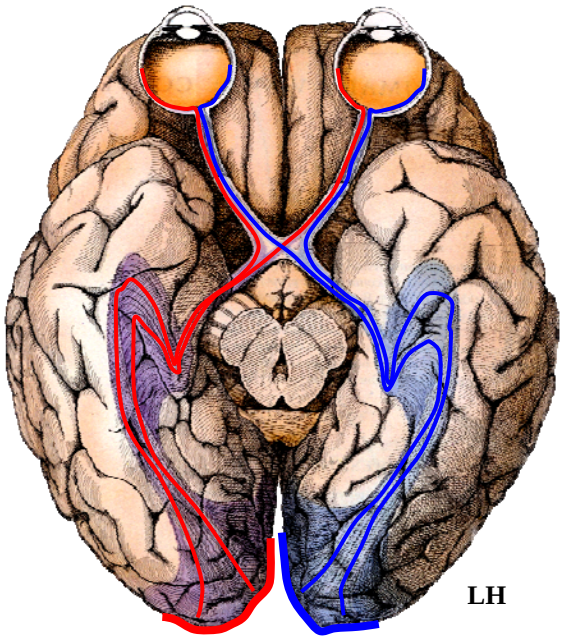


The visual brain does a great deal of processing: Lightness perception

(Anderson and Winawer)

The chess pieces are the same shade of gray; really.



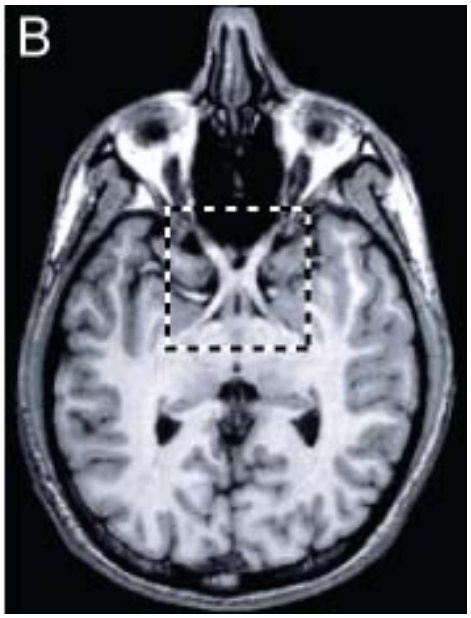


Visual pathways

Right visual field

Left visual field

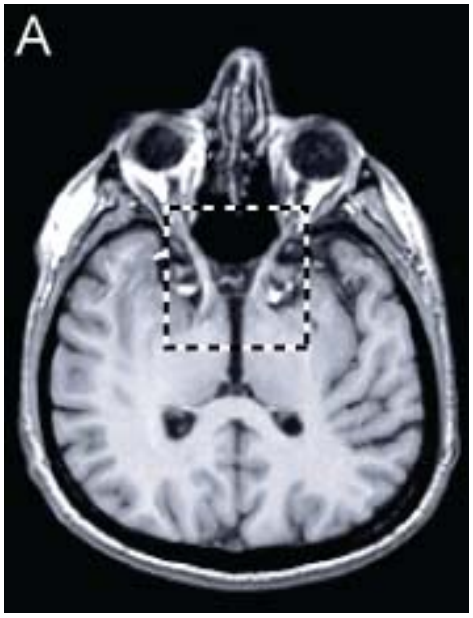
Serge Dumoulin



Conventional optic chiasm

Control

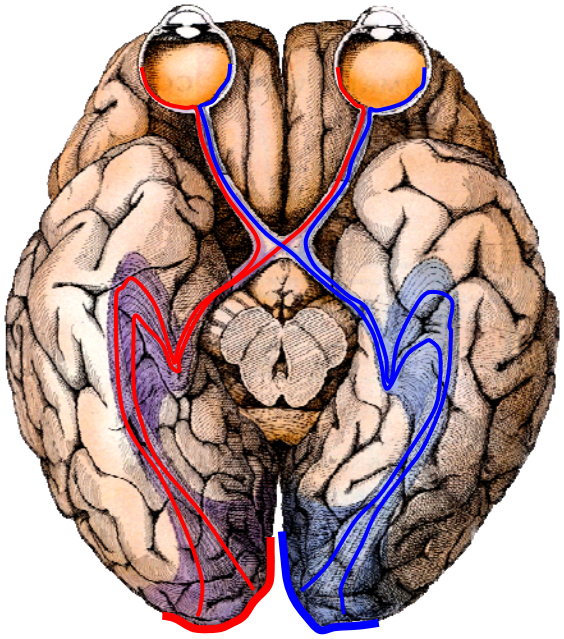
Serge Dumoulin



Missing optic chiasm

Achiasma

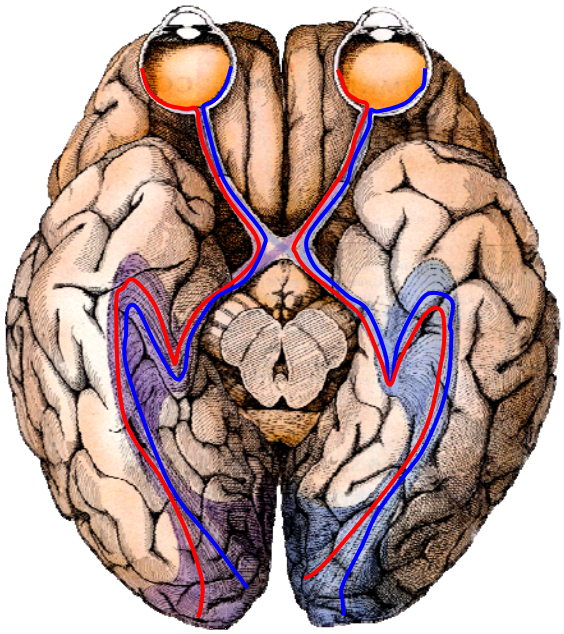
Normal



Right visual field

Left visual field

Achiasmic

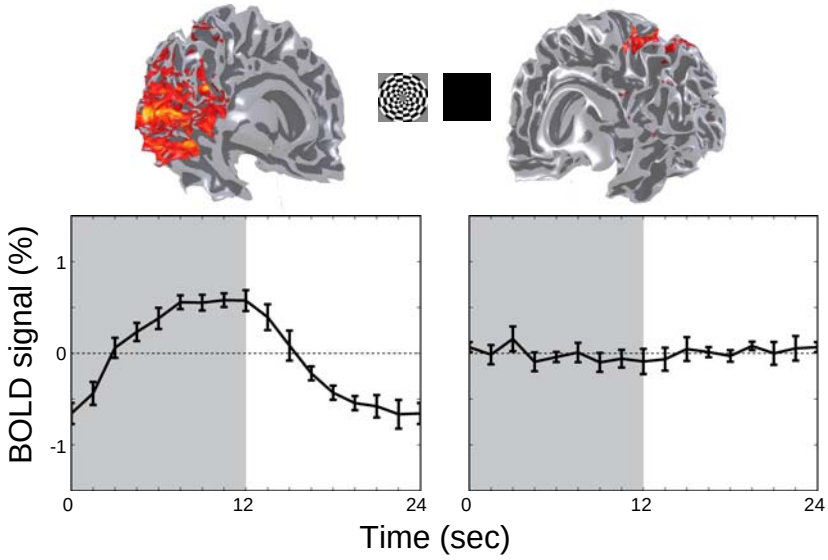


Right visual field

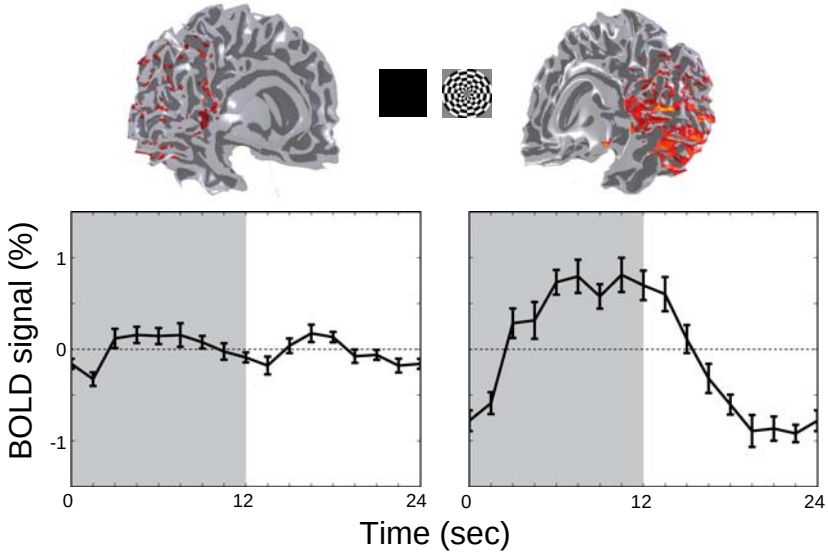
Left visual field

Apkarian et al., E.J.N. 1994
Apkarian et al., Brain, 1995
Victor et al., Cer. Cortex, 2000
Jansonius et al., JNO, 2001
Prakash et al., JNO, 2009

Left eye stimulation

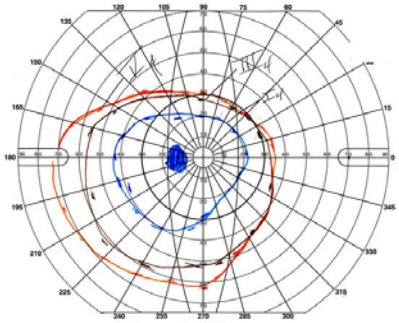


Right eye stimulation

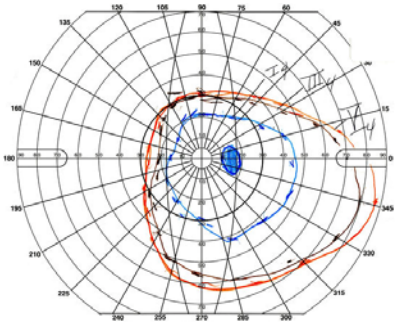


- Slight decrease in visual acuity
- Slightly reduced peripheral visual fields
- No stereopsis
- Prominent infantile and see-saw nystagmus that went away

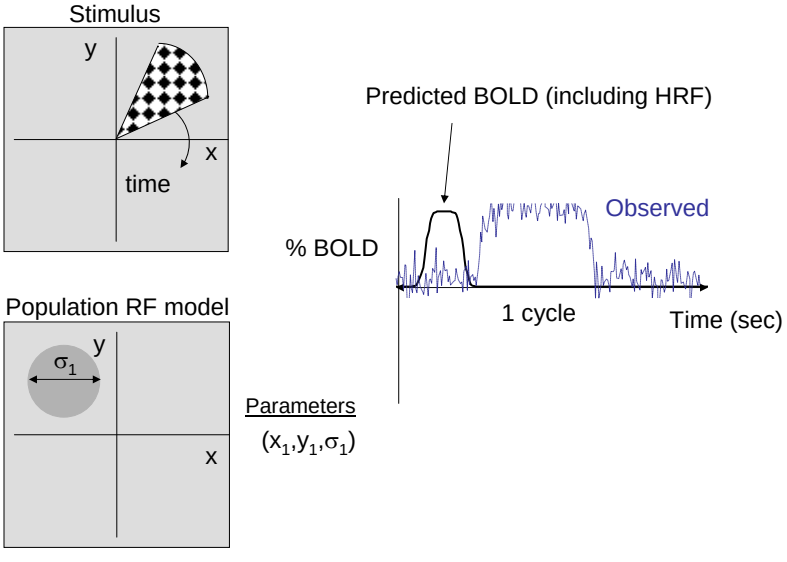
Left eye



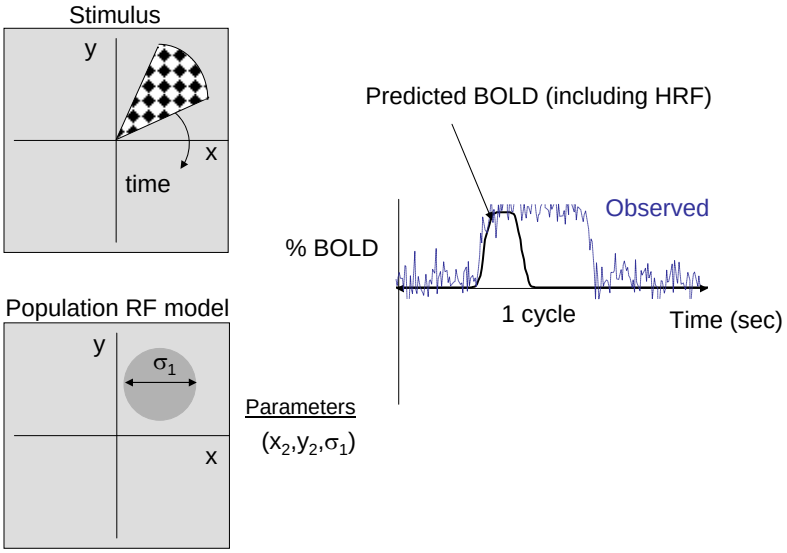
Right eye



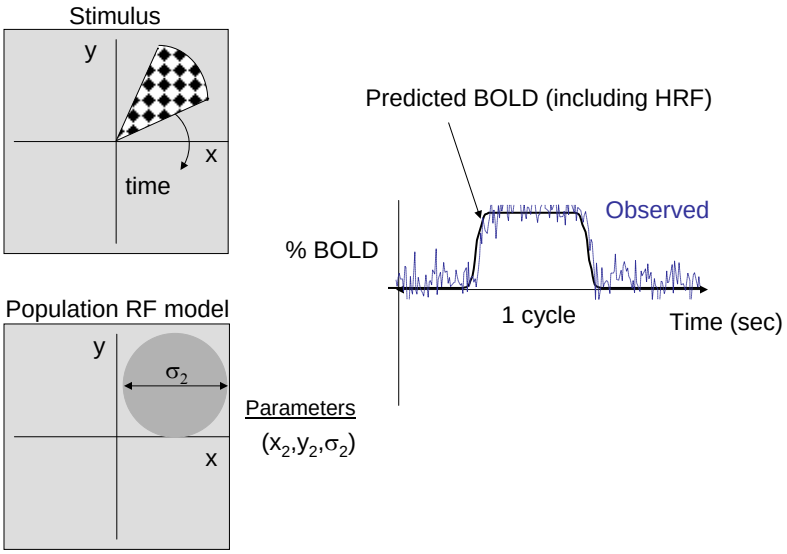
Population RF estimation



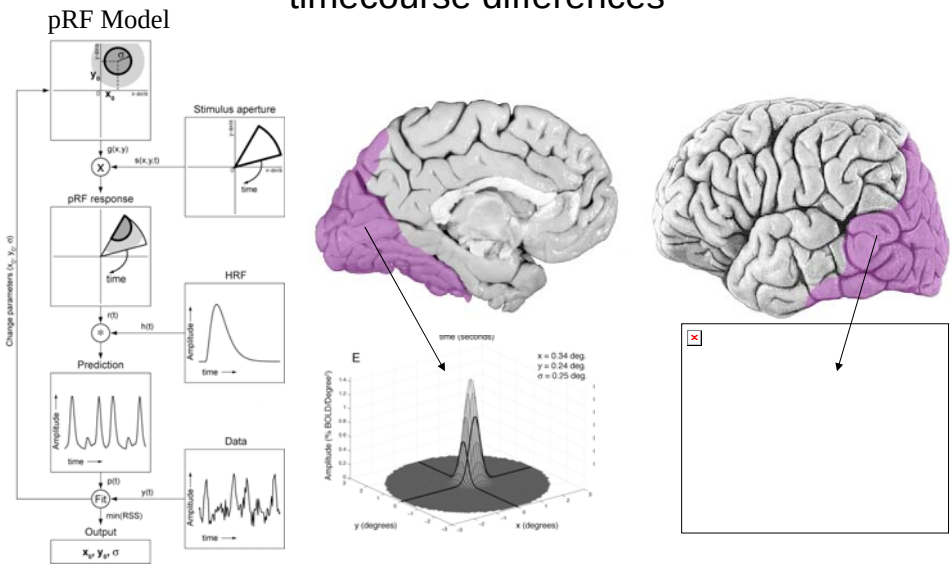
Population RF estimation



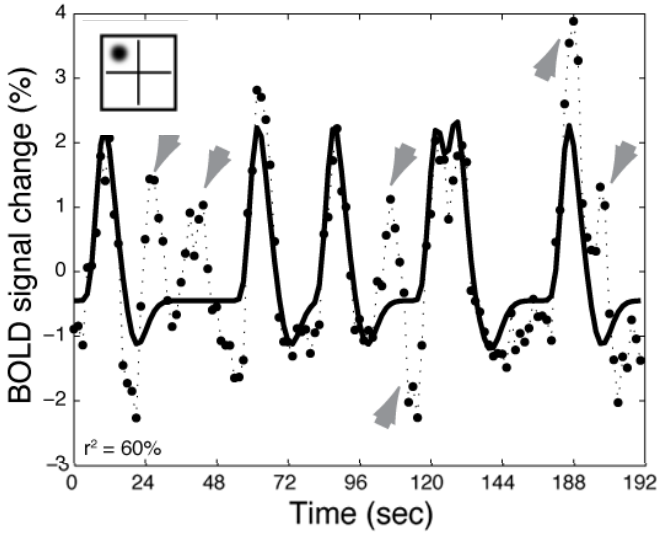
Population RF estimation



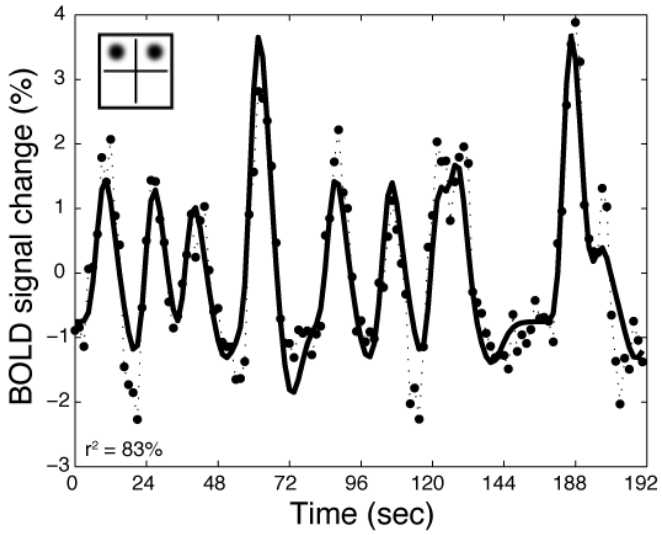
Population receptive field models interpret timecourse differences



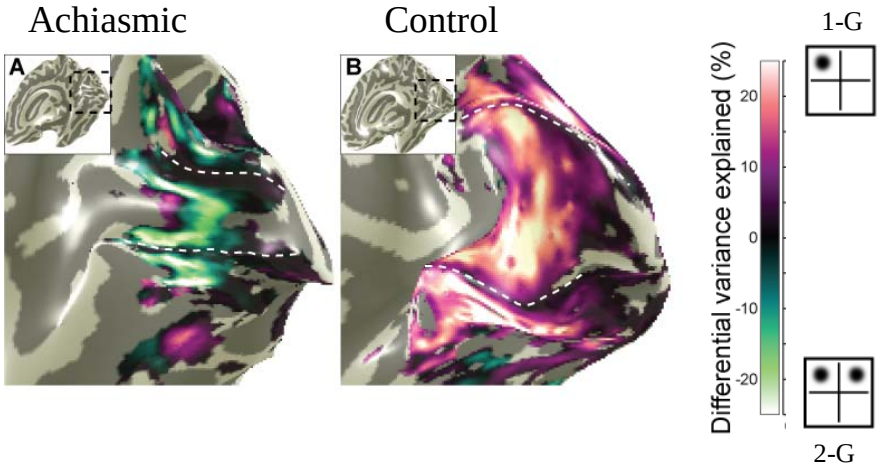
Modeling the time course (1G)

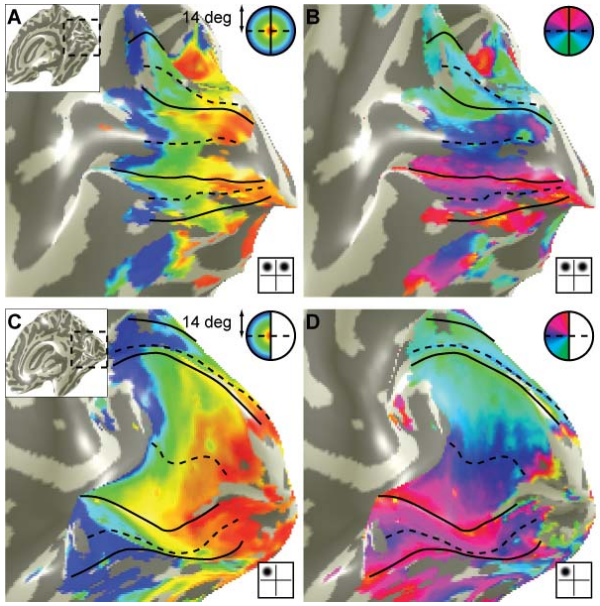


Modeling the time course (2G)



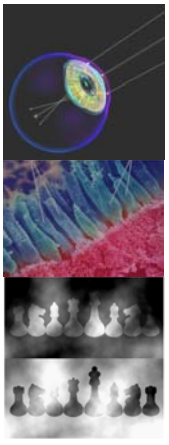
2-G is better except at vertical midline (doh)

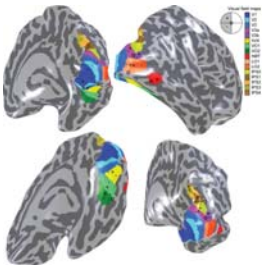




Albinos (Morland)
Hemispheric agenesis (Muckli)

Review





Many important features of visual cortex have their origins in the encoding and processing in the retina

There is an enormous expansion of processing power in the cortex, with many specializations to interpret the retinal signal.

We hope to understand which major cortical features are essential for this interpretation process (achiasmic – map). Clarifying this process is essential to understand vision.

Color Appearance Depends On The Spatial Pattern Across The Cone Mosaic

(Shevell and Monnier)